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A Human Factors Engineering Assessment of the Buffalo Mine Protection Clearance Vehicle Roof Hatch

by Asisat F. Animashaun

ARL-TR-4272 **October 2007**

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A Human Factors Engineering Assessment of the Buffalo Mine Protection Clearance Vehicle Roof Hatch

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14. ABSTRACT

The project was initiated at the request of two platoons of Combat Engineers, military occupational specialty 21B, who serve as part of the Kansas National Guard. The U.S. Army Research Laboratory's (ARL's) Human Research and Engineering Directorate performed an evaluation of the emergency egress characteristics of the Buffalo. ARL developed a plan to evaluate the emergency egress characteristics of the Buffalo using human figure modeling. A detailed analysis of the vehicle roof hatch was performed to identify whether the larger end of the male Soldier population, with equipment and clothing, could fit through the hatch. The results of the egress modeling identified some shortcomings with the emergency egress characteristics of the Buffalo and two recommendations were made: (1) increase the hatch size to 69 cm by 50 cm or (2) use a circular hatch with a diameter measuring 61 cm instead of a rectangular or square hatch. The results and recommendations from the modeling were used to help drive design modifications that, if implemented, could enhance the emergency egress characteristics of the Buffalo.

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1. Introduction

1.1 Background

The Mine Protection Clearance Vehicle, also called the Buffalo (see figure 1), is the Army's answer to defeat improvised explosive devices (IEDs). Pentagon records show that since the wars in Afghanistan and Iraq began, 1,074 troops have been killed and 11,513 others wounded by insurgent bombs (Brook, 2006). The heavily armored 23-ton Buffalo vehicle is used for point, route, and area clearance of mines and explosive devices and is virtually indestructible. The vehicle design is similar to a boat with a V-shaped hull that is constructed to deflect the force of an explosion away from the vehicle, reduce vehicle rollover, and withstand as much as 45 pounds of explosives (Force Protection, 2006). There have been approximately 1000+ IED hits in a Buffalo without any loss of life (Defense Update, 2004).

Figure 1. Buffalo exterior (Force Protection Inc. 12, Dec. 2006. http://www. forceprotectioninc. com/models/Buffalo/).

The Buffalo is designed to seat six, with the driver and claw operator in the front, and the remaining four Soldiers in the rear of the vehicle searching for possible roadside bombs or IEDs. The Buffalo's role is to function as the lead vehicle during patrols, clearing routes of possible explosive devices in 12-hour shifts. After a suspected IED is detected, the claw operator maneuvers the 30-foot extension, called the iron claw, to clear the area around the device to get a closer look. The claw is equipped with a 200X zoom camera and sensory equipment which allows personnel to inspect possible IEDs. After an IED is identified, disposal is then coordinated with an explosive ordnance disposal team.

In terms of ingress and egress, there are six top-side hatches and one rear door. Egress consists of the crew moving from within the vehicle cab to the roof of the vehicle through a hatch, and ingress consists of the crew moving from the exterior of the vehicle to the interior cabin through a top hatch. The rear door is used for normal egress situations. Large armored glass windows line the perimeter of the vehicle and provide visibility to the sides and front of the vehicle but are not accessible as an emergency exit. Emergency egress entails a quick exit of the vehicle during conditions attributable to an unforeseen event that requires immediate action in order to minimize or avoid considerable physical harm. In an emergency situation when the rear door is inaccessible, the only other route of escape would be through a roof hatch, as shown in figure 2.

Figure 2. External hatch view.

The roof hatch measures 50 cm by 50 cm square with rounded corners and is positioned over the occupant seats (see figure 3).

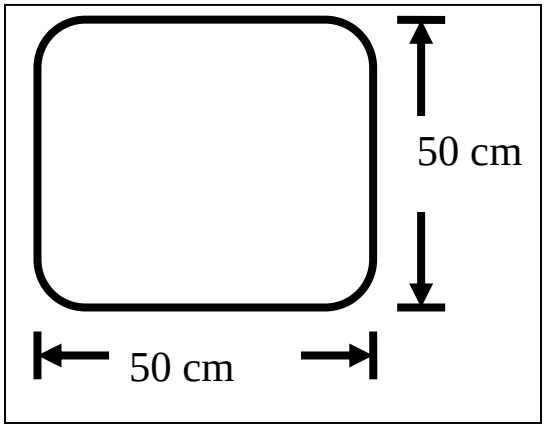

Figure 3. Buffalo hatch dimensions.

This design may lead to serious human factors issues: a) would a Soldier be able to quickly evacuate or enter the vehicle while wearing full combat protection, and b) how easily would the Soldier be able to egress if injured? The hatch is designed to serve primarily as an emergency exit while the vehicle is stationary. In addition to this primary function, the hatch serves an unintended secondary function as a shooting platform to return fire while the vehicle is moving.[1] In this manner, during various circumstances, there are several accounts reporting egress as extremely difficult. As reported by subject matter experts (SMEs), the added bulk of body armor (particularly on the upper arms) and vehicle movement made it very difficult to egress during normal operational conditions. Although the hatch was not designed to function as a shooting platform, the present analysis takes this scenario into consideration (see figure 4).

Figure 4. Six top side hatches (Force Protection Inc. 12, Dec. 2006. http://www.defensereview.com/modules.php?name=News&file=article&sid=808).

1.2 Purpose

The purpose of this analysis was twofold: to determine if (a) the hatch design of the Buffalo conforms to the human factors design standard for escape hatches and (b) the design standard accommodates clothing and equipment (DoD Human Engineering Design Criteria Standard, 1999). An analysis will determine if the hatch openings are sized to permit operators to easily ingress and egress the vehicle with full body armor and clothing during an emergency situation

[1]Future versions of the Buffalo may have a turret as an additional feature.

when the rear door is inaccessible. Body armor, clothing, and other combat gear add additional bulk to the Soldier and may prevent egress. This is corroborated by several accounts from SMEs of the 772nd Engineering Company, who recounted their difficulty in returning fire because of combat armor, large shoulder width (bi-deltoid breadth), and carrying a weapon. This report is intended to identify if the Buffalo is within MIL-STD-1472F guidelines. If designed within the guidelines of MIL-STD-1472F, the analysis may reveal a possible need for revision (DoD Human Engineering Design Criteria Standard, 1999).

2. Method

To evaluate the hatch, the following issues were analyzed: (a) hatch sizing standards, (b) the effects of clothing ensembles on ingress and egress, and (c) hatch shape. Not considered in this analysis are posture, anthropometry of the Soldier in relation to the hatch interface, and biomechanics attributable to vehicle motion. Consideration of these factors would have exceeded resources and the project scope for the analysis and are therefore not included.

An integrated human figure modeling analysis approach was used to analyze the hatch design (Lockett & Kozycki, 2005). The basic steps of the analysis were

- Determining the critical anthropometric dimensions associated with the analysis.
- Developing a properly sized and equipped human figure model.
- Modeling the human figure model in the various hatches.

2.1 Anthropometric Data

The two largest body dimensions that may pose potential issues with Soldier ingress and egress are bi-deltoid breadth and chest depth. Shoulder breadth or bi-deltoid breadth was the largest body dimension that could possibly hinder Soldier ingress and egress. To accommodate 99% of the population in the one dimension, an unclothed boundary figure (Bittner et al., 1987) with bi-deltoid measurements of 56 cm (22 in.) was used for the analysis. The bi-deltoid breadth is a measure of the point-to-point distance between right and left deltoid points. The deltoid point is the point at which there is the most protrusion on the upper arm (Gordon et al., 1989). Chest depth is a horizontal measure of the chest taken front to back from the bustpoint to the back at the same level (Anthropometric Survey [ANSUR], 1988). Clothing and the load-bearing vest (LBV) increase chest depth approximately 7 cm to 38 cm and may potentially cause issues with Soldier ingress and egress.

2.2 Human Figure Modeling

Human figure modeling was used to determine if the larger end of the Soldier population could easily fit through the hatch. The modeler used Jack[2] human figure modeling simulation software to perform the Buffalo modeling analysis. Jack allows one to import clothing and equipment created in other computer-aided design software to simulate a real environment.

A fully clothed human figure with bulky clothes and equipment was used for this assessment because clothing may have a disadvantageous effect on egress. The figure was sized to represent the worst case scenario of a Soldier with the largest body proportions found within the male and female target audience.

2.2.1 Clothing Effects

In order to develop an accurate model, information about all of the equipment worn and carried by the Soldier was obtained through an interview with a military occupational specialty 21, combat engineer Buffalo crew member. Clothing and equipment items are listed in table 1.

Table 1. List of worn combat equipment.

Clothing	**Equipment**
Army Combat Uniform (ACU) - Jacket - Trousers - Nylon Belt - T-Shirt - Undergarments	Seven ammunition magazines- worn on chest
Boots, Socks	Intercom radio - worn on shoulder
Helmet	Multipurpose-tool - under belt
Interceptor Body Armor	Global Positioning System - trouser pocket
Helmet	M-16
LBV	

The equipment list was then used to find matching or approximate matches for existing equipment and clothing already modeled by ARL in Jack used in the human figure model. Digitized clothing items (the battle dress uniform [BDU] shirt and trousers, body armor, helmet, boots, and a body armor vest) were then added to the human figure model. As a result, the critical bi-deltoid breadth dimension increased.

The interior hatch dimensions measure 50 cm by 50 cm square with rounded edges are are shown in figure 5. The roof hatch in relation to seating and occupant size is demonstrated.

[2]Jack is a registered trademark of Unigraphics, Inc.

Figure 5. Internal hatch view.

2.3 Hatch Size Standards

Two Department of Defense human factors design sources for standard hatch design were consulted: MIL-STD-1472F (table 2) and MIL-HDBK-759C (table 3). MIL-STD-1472F whole body access opening measurement orientations are shown in figure 6. These human factors engineering design guidelines are used in the design of all Army facilities, equipment, and, systems. MIL-STD-1472F recommends a minimum hatch size for ingress/egress for regularly and heavily clothed personnel. Since the Soldiers are in full combat uniform with armor, the heavily clothed dimensions were used as a guideline for the analysis. In accordance with MIL-STD-1472F, the depth of the Buffalo hatch exceeded the standard by 9 cm, while the width was 19 cm less than the recommended length.

The MIL-STD-1472F recommendation for a circular hatch is 61 cm in diameter. Contrary to MIL-STD-1472F, MIL-HDBK-759C recommends a square opening with lengths measuring 56 cm, which is less than the MIL-STD-1472F recommendation for a regularly clothed individual. This handbook does not appear to incorporate a clothing allowance.

Table 2. MIL-STD-1472F whole body access opening dimensions.

Dimensions	**1. Depth**		**2. Width**	
Clothing	Light	Bulky	Light	Bulky
Top/Bottom Access	33 cm	41 cm	58 cm	69 cm

Table 3. MIL-HDBK-759C hatch opening dimensions.

	Minimum (cm)	**Preferred (cm)**
Rectangle	40.5x61	51x71
Square	46	56
Round (diameter)	61	24

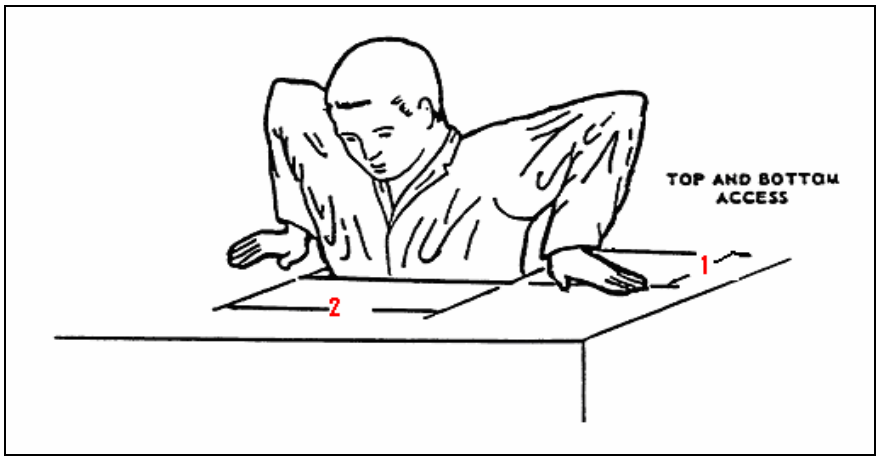

Figure 6. MIL-STD-1472F whole body access opening (http://hfetag.dtic.mil/docshfs/mil-std-1472f.pdf).

The hatch opening was modeled with Jack. The male was clothed in complete ACU, body armor, and personal protective equipment to simulate battle environment conditions. Based on interview data, the basis for the broadest body dimension on a large male figure was the bi-deltoid breadth, and special consideration was given to this area. The clothed model was then postured and manipulated in the following four hatches:

1. 50-cm by 50-cm hatch - corresponds to current hatch size and shape;
2. 41-cm by 61-cm hatch - corresponds to MIL-STD-1472F recommendations;
3. 50-cm by 69-cm sized hatch - interpolated from current hatch and MIL-STD-1472F heavily clothed standards;
4. 61-cm diameter round hatch - MIL-STD-1472F corresponds to MIL-STD-1472F recommendations, and conclusions were drawn based on the analysis.

3. Results

Figures 7 through 18 depict the clearance dimensions for the various hatch sizes: current Buffalo design, MIL-STD-1472F rectangular hatch, 50-cm by 69-cm rectangular hatch, and MIL-STD-1472F 61-cm round hatch. During their 12-hour rotating shifts, Soldiers often have to return fire while the vehicle is moving. Vehicle movement, coupled with a small hatch size places an added constraint during vehicle egress and is considered in this analysis for all hatch configurations.

3.1 50-cm by 50-cm Hatch

In addition to bi-deltoid breadth, chest depth is another critical body dimension affecting ingress and egress. Chest depth is a horizontal measure of the chest taken front to back from the bust point to the back at the same level (ANSUR, 1988). Clothing and the LBV increase chest depth approximately 7 cm to 38 cm. A Soldier in combat gear will have a difficult time exiting the vehicle through a 50-cm by 50-cm hatch and will have to maneuver to egress or ingress the Buffalo. It is assumed that the Soldier would emerge through the hatch with arms crossed to reduce shoulder width (refer to figure 7).

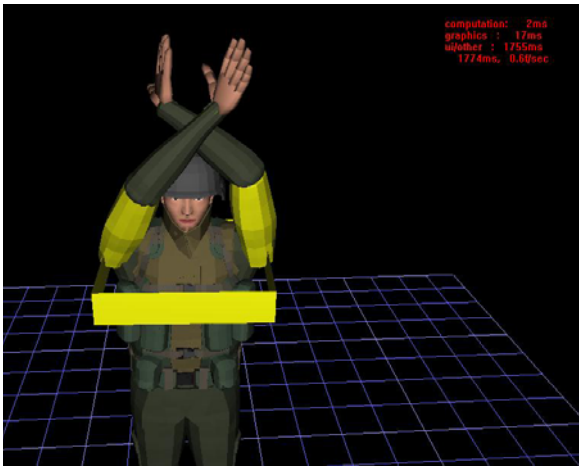

Figure 7. Shoulder hatch contact, 50 cm by 50 cm.

Assuming that the vehicle is stationary, egress and ingress are possible when a body is angled to the side of the hatch, as in figure 8. Compression of the shoulders is minimal.

In figures 7 and 9, it is evident that the hatch is not wide enough if the arms are stretched upward or in a relaxed position. Both shoulders come in contact with the sides of the hatch because of body armor, clothing, and body size.

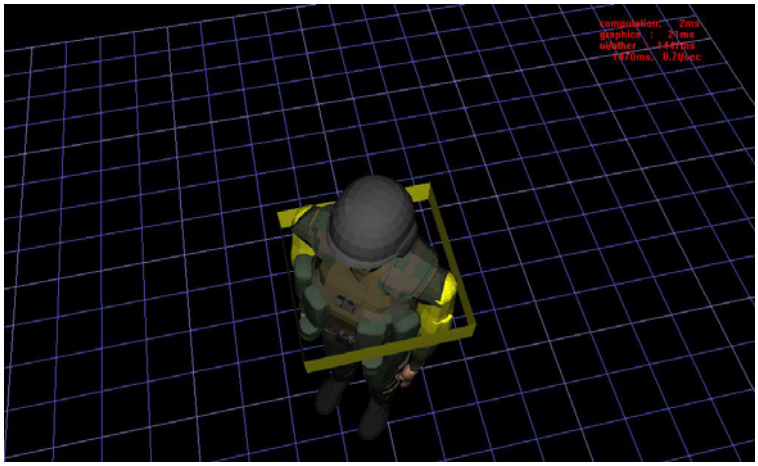

Figure 8. Angled to sides, 50 cm by 50 cm.

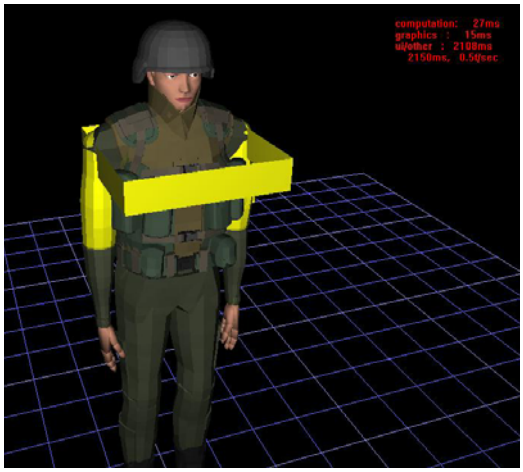

Figure 9. Relaxed position, 50 cm by 50 cm.

A Soldier can fit through the hatch facing parallel to the sides of the hatch; however, egress would require the Soldier to contort. Equipment, clothing, and the Soldier's body would be compressed against the sides of the hatch opening; therefore, this is not an ideal egress position for a 50-cm^2 sized hatch. In the parallel position, there is clearance on the sides of the torso only after the shoulders clear the hatch, as shown in figure 10.

Egress in the diagonal position is simpler than in the parallel position since there is more room for the shoulders to clear the hatch, as shown in figure 8, and is therefore an ideal egress position. There is still compression, although slight, which requires the Soldier to contort his body, either emerging with arms crossed or with one arm at a time, as shown in figure 11.

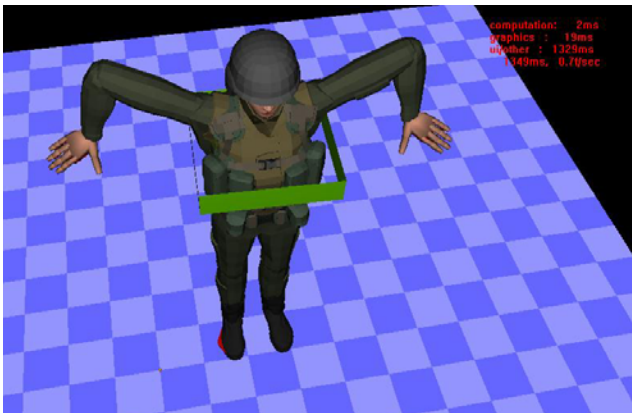

Figure 10. Side clearance of torso 50 cm by 50 cm.

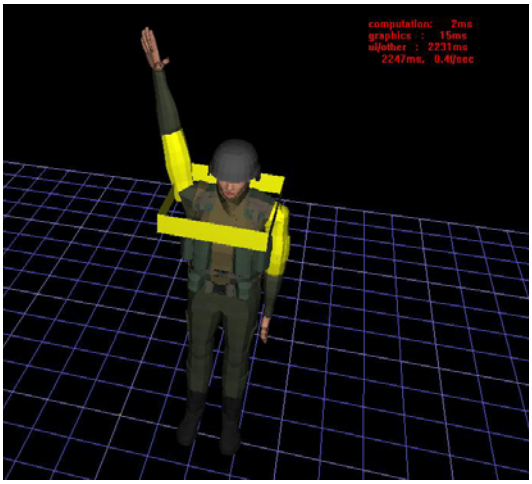

Figure 11. One-armed egress.

If the Soldier makes contact with the front of the hatch, as shown in figure 12, there is a clearance of 11 cm in the rear. (There is no side shoulder clearance in this position.)

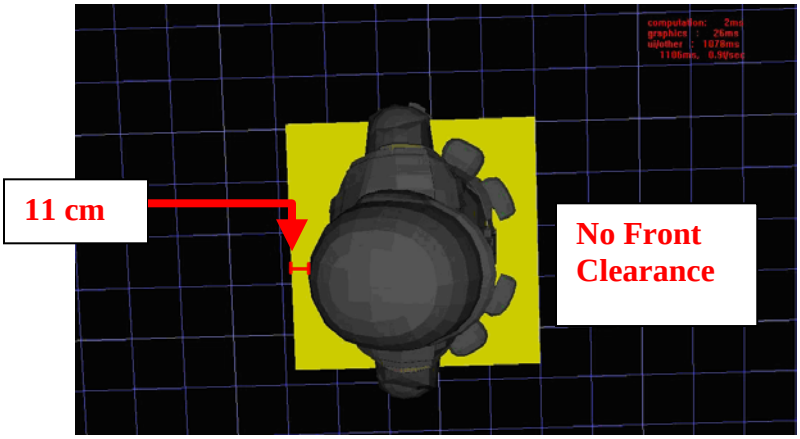

Figure 12. 50-cm by 50-cm hatch parallel to sides.

Figure 13 depicts diagonal hatch measurement dimensions. Given that the shoulder breadth of the Soldier is 56 cm, there should be adequate room for the shoulders to clear the hatch according to MIL-STD-1472F, but there is compression of the chest area because of the increased chest depth caused by clothing and armor.

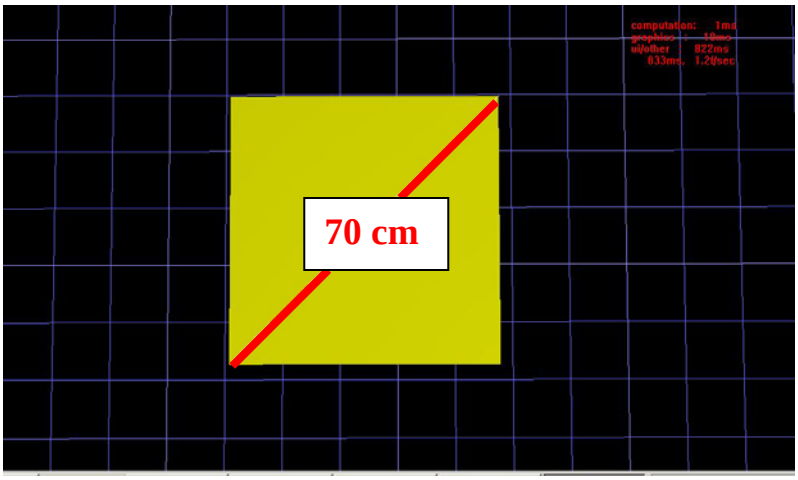

Figure 13. 50-cm by 50-cm hatch diagonal to sides measure.

There is compression of the chest area because of the increased chest depth caused by clothing and armor, as shown in figure 14.

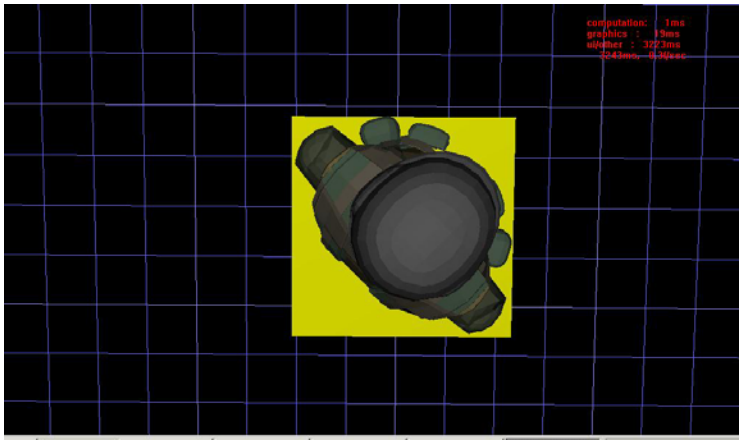

Figure 14. 50-cm by 50-cm hatch body diagonal to sides.

3.2 MIL-STD-1472F 41-cm by 61-cm Hatch

If the Soldier were positioned as shown in figure 15, the MIL-STD-1472F hatch side and rear clearance are 11 cm and 4 cm, respectively. The side clearance is adequate, but the rear clearance is extremely small. Given the Soldier's need to ingress and egress the vehicle with a weapon and also maintain the standing position in the hatch to return fire while moving, a clearance size of 4 cm does not allow for ideal ingress and egress.

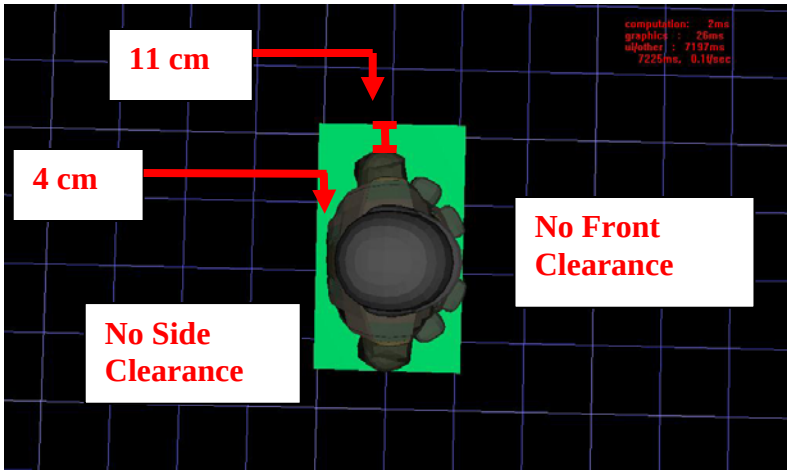

Figure 15. MIL-STD-1472F 41-cm by 61-cm hatch side clearances.

3.3 50-cm by 69-cm Hatch

If the Soldier were making contact with the front of the hatch, as shown in figure 16, the recommended hatch size is 50 cm by 69 cm and the side and rear clearance are 13 cm and 12 cm, respectively, which provide adequate clearance on all sides of the body and allow for ideal ingress and egress.

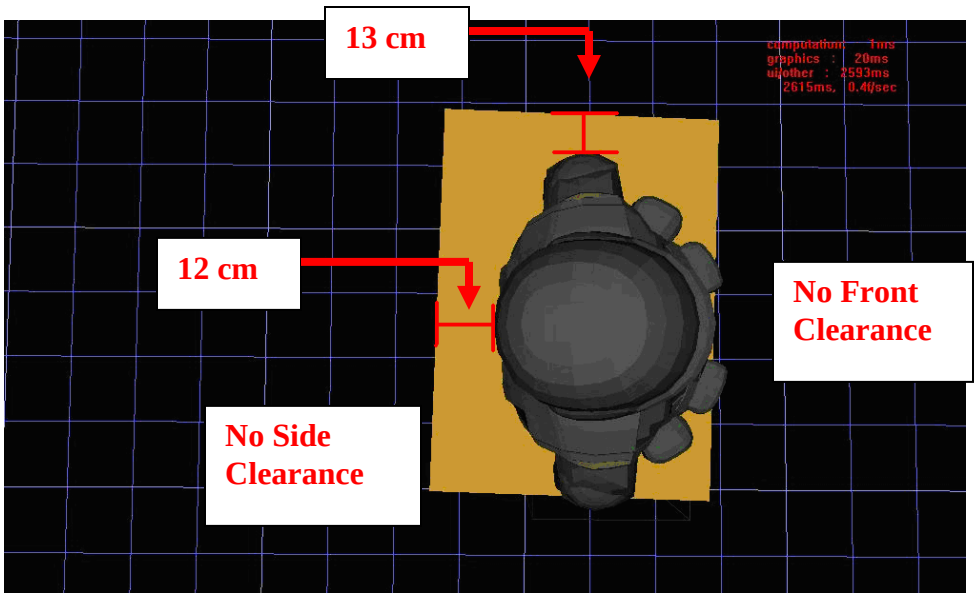

Figure 16. 50-cm by 69-cm hatch side clearances.

Even when angled diagonally to the sides of the hatch, the Soldier has sufficient clearance to freely ingress and egress the vehicle if the hatch size is 50 cm by 69 cm, as shown in figure 17.

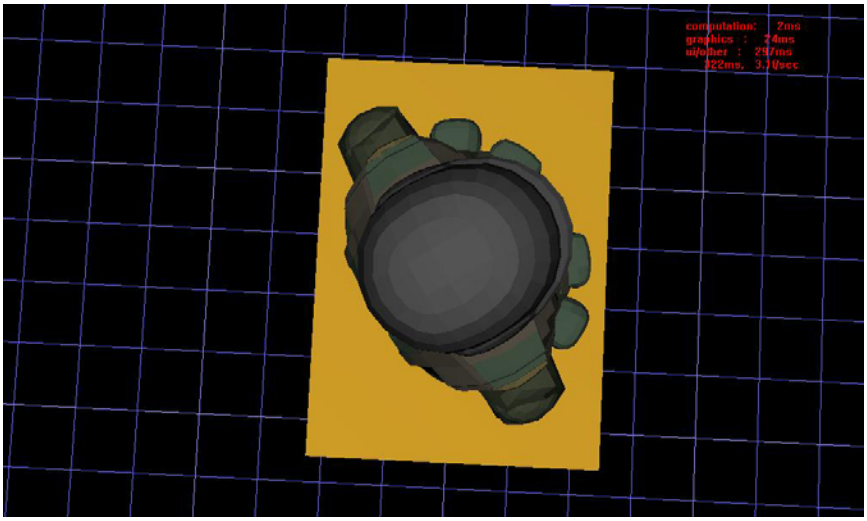

Figure 17. 50-cm by 69-cm body diagonal to sides.

3.4 MIL-STD-1472F 61-cm-Diameter Round Hatch

An alternate solution is to modify the hatch shape to a circle. Armored vehicles such as the M1 Abrams and M2/M3 Bradley, feature oblong or semi-circular roof hatch designs. MIL-STD-1472F requires a minimum of 61 cm (24 in.) in diameter for circular hatches, as shown in figure 18. This size would be sufficient for rapid egress in full combat gear. At minimum, a circular hatch should be 60 cm (~23.6 in). However, any modifications to increase the hatch size should consider the likelihood of a) weakening the overall integrity of the roof, b) reducing the total number of roof hatches because of space limitations, and c) increasing the force required by a Soldier to open or close the hatch.

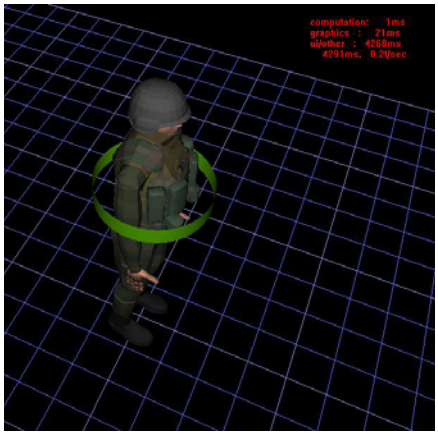

Figure 18. 61-cm-diameter hatch.

4. Discussion

Based on the human figure modeling analysis, larger Soldiers can fit through a hatch (50 cm^2) in size but with minimal clearance on all sides and awkward positioning especially in the parallel position. This is consistent with SME input. Soldiers would have to contort their bodies and lift themselves through the hatch one arm at a time. The solution for this issue is to angle the body across the diagonal of the hatch opening during egress and ingress. My recommendation for MIL-STD-1472F is that combat gear should be taken into account in the design specifications of the hatch. Given the current design, depending on orientation to the length or width of the hatch, the Soldier contact with the sides of the hatch during ingress and egress is considerable. In an emergency situation when traditional egress is not possible, a suitable alternate emergency exit that facilitates a rapid egress is necessary. Possible solutions for this issue are to increase the size of the rectangular hatch or make the hatch opening circular. The 50-cm by 69-cm hatch offers the most clearance room of the rectangular hatches. A circular hatch would have to be sized according to military standards at 61 cm in diameter and would offer an equal clearance around the Soldier's body, regardless of orientation. From modeling results, a rectangular hatch of 50 cm by 69 cm in size is adequate for easy ingress and egress and is recommended for accommodating bulky clothing and equipment. The analytical results recommendation is supportive of a rectangular hatch opening with dimensions ≥50 cm by 69 cm.

5. Recommendations

Based on the human figure modeling analysis, there are two possible solutions to allow for easier ingress and egress to the Buffalo: (a) increase the hatch size to 69 cm by 50 cm or (b) use a circular hatch with a diameter measuring 61 cm instead of a rectangular or square hatch.

A revision of the MIL-STD-1472F hatch design standard for bulky clothes is necessary to reflect the need for additional consideration of combat gear and additional equipment such as a cold weather clothes, water bags, or chemical protective suits. The current guideline recommends 41 cm depth and 69 cm width for heavily clothed individuals. Based on modeling results, it is recommended that a rectangular hatch size of 69 cm by 50 cm would be adequate for easy ingress and egress.

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Acronyms

ACU	Army Combat Uniform
ANSUR	anthropometric survey
ARL	Army Research Laboratory
BDU	battle dress uniform
DoD	Department of Defense
IED	improvised explosive device
LBV	load-bearing vest
MIL-STD	Military Standard
MIL-HDBK	Military Handbook
NBC	nuclear, biological, and chemical
SME	subject matter expert

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